

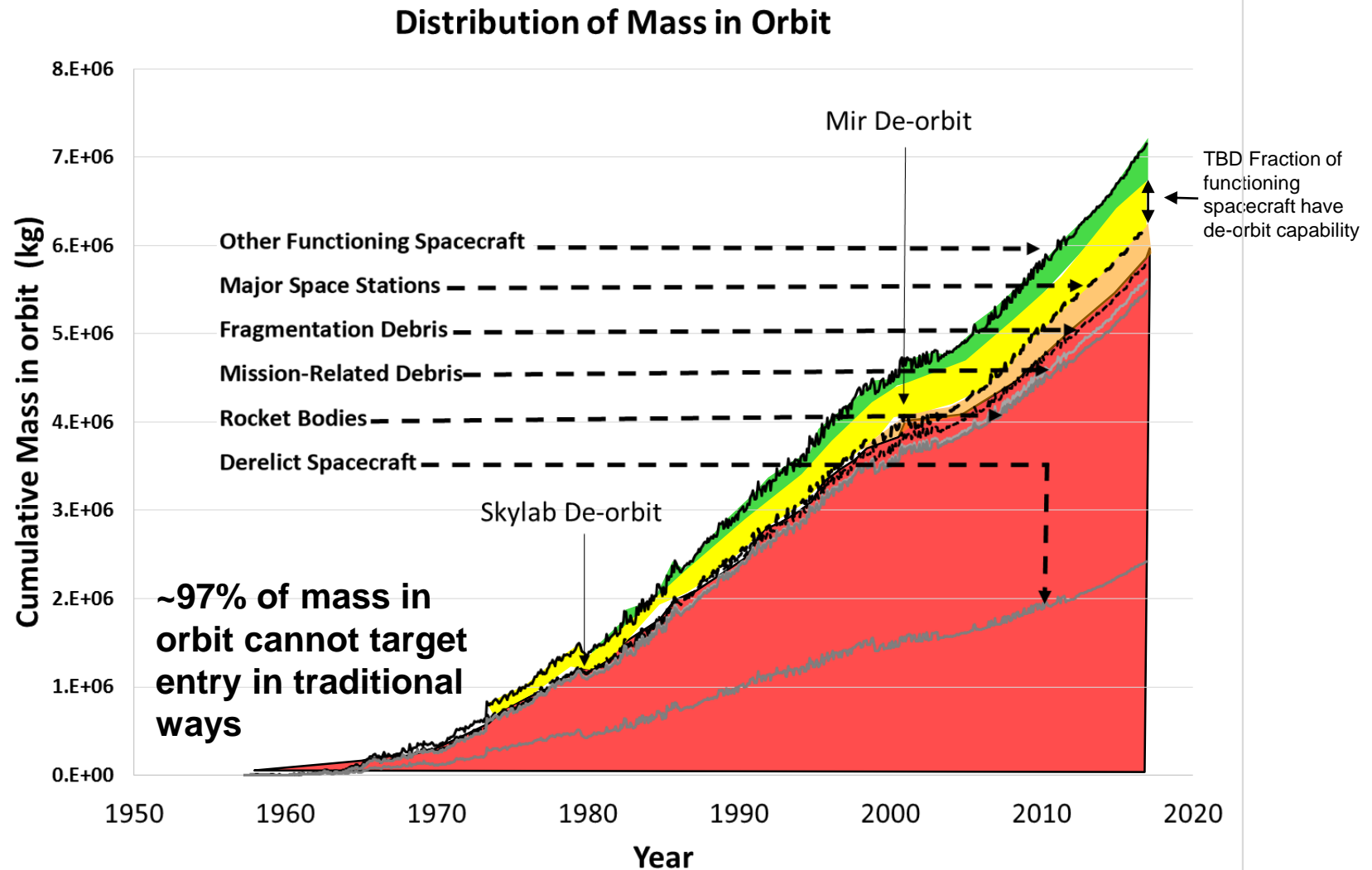


Minimum ΔV for Targeted Spacecraft Disposal

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Mass in Orbit





Two Approaches to Stormy Seas:

Shipwreck, 1854 - Ivan Aivazovsky



Let the environment
determine your fate

Use the environment to
determine your fate



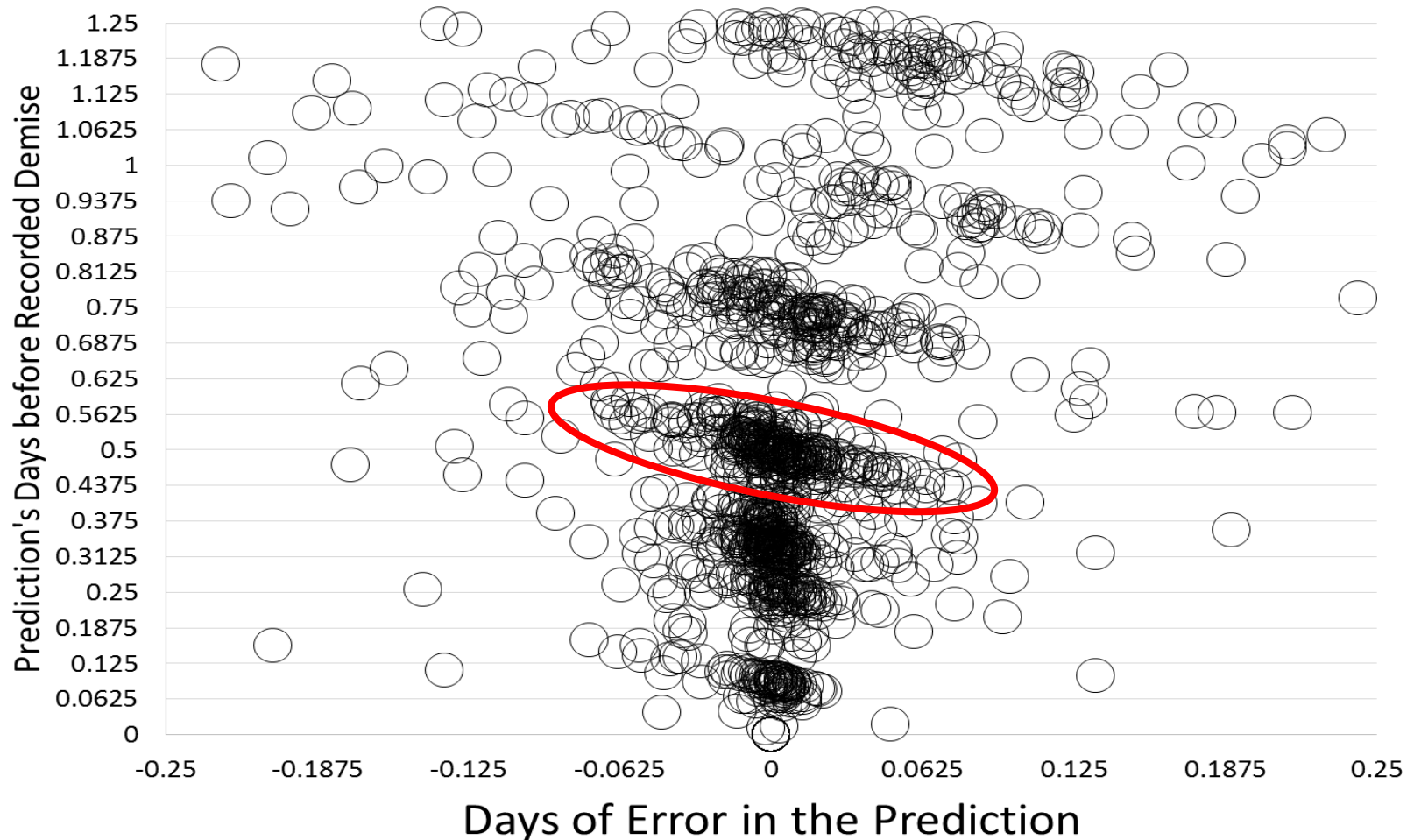
Corey Wilson/CNN

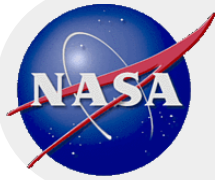
COURTESY COREY WILSON



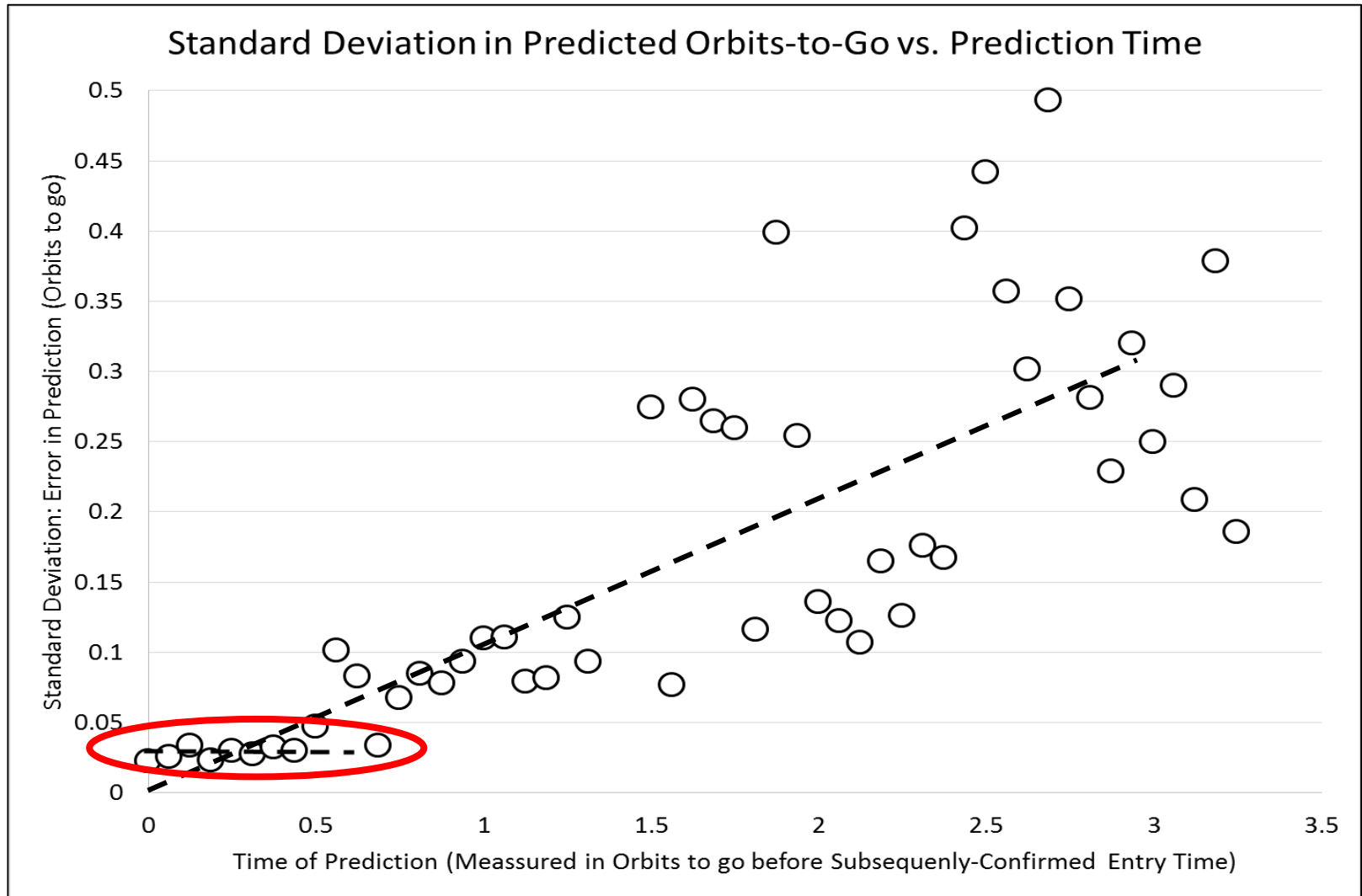
Random Entry Forecast Errors

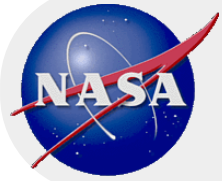
Historical Error In Non-Cooperative Decay Predictions



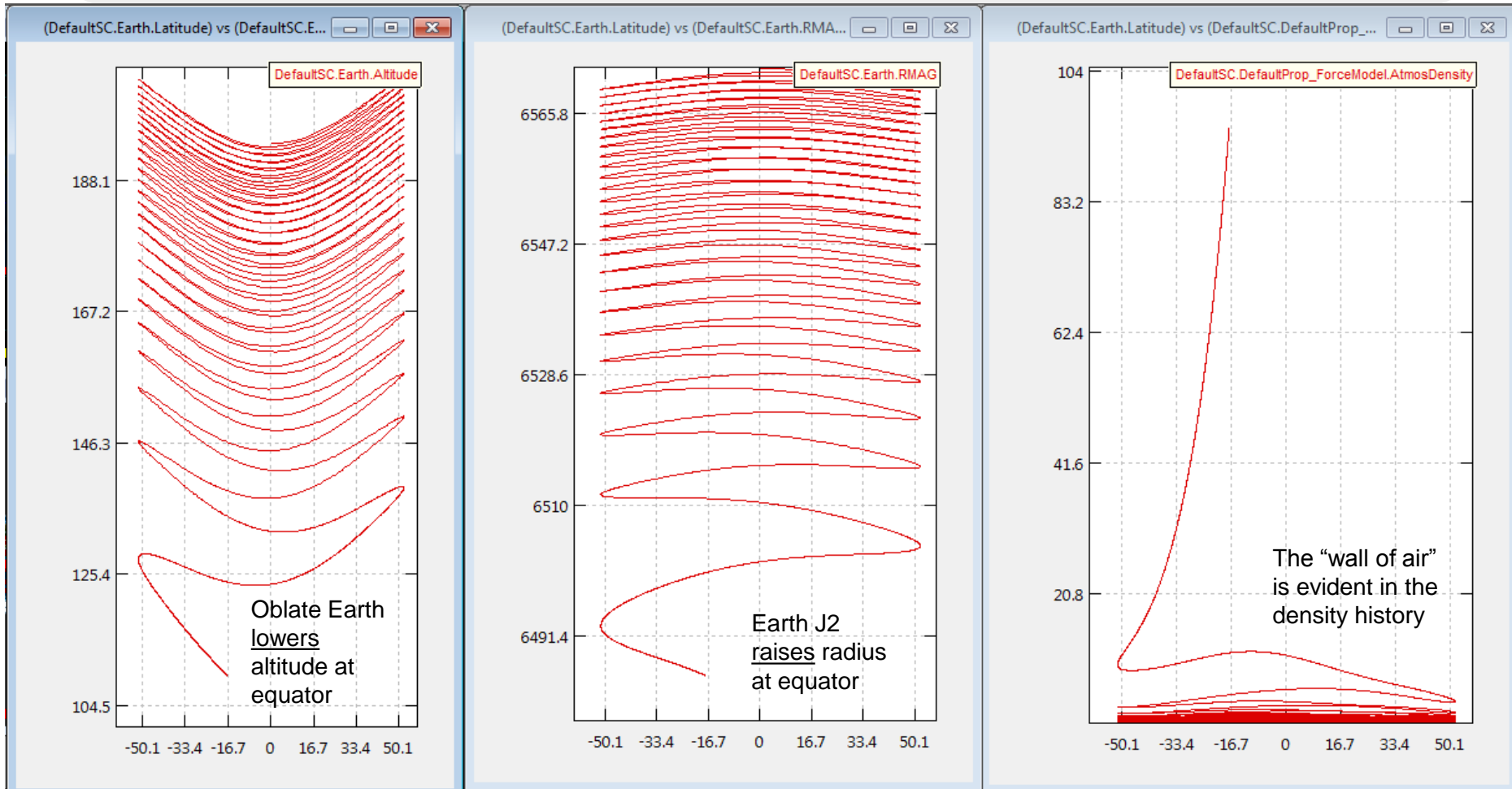


Error Shrinks, But Doesn't Vanish





Example Final 36 hours of SL4 Decay (Simulated)



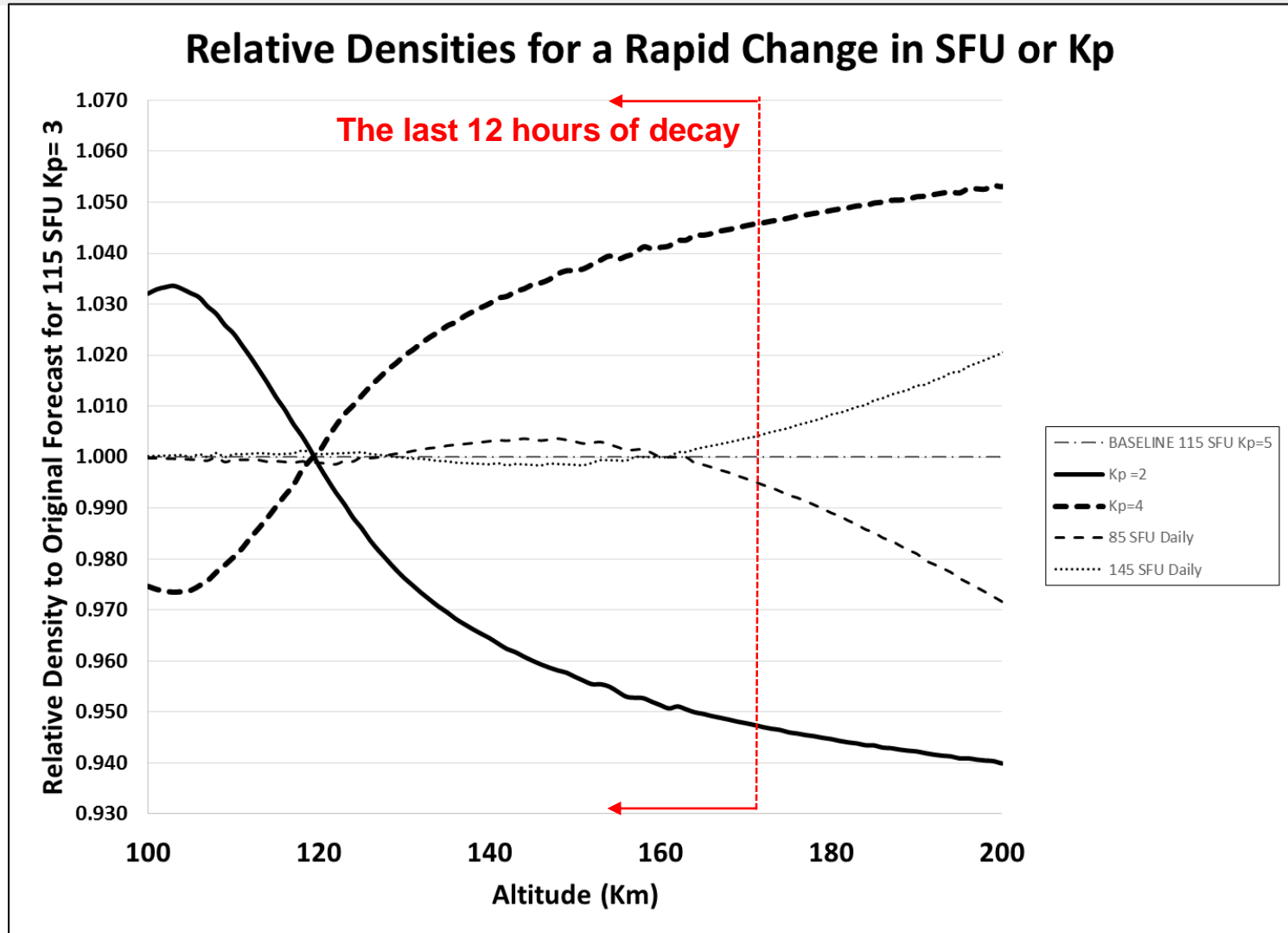
Altitude Km
vs Latitude

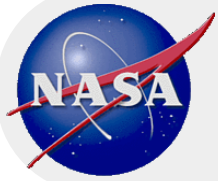
Radius Km
vs Latitude

Atm. Density
vs Latitude

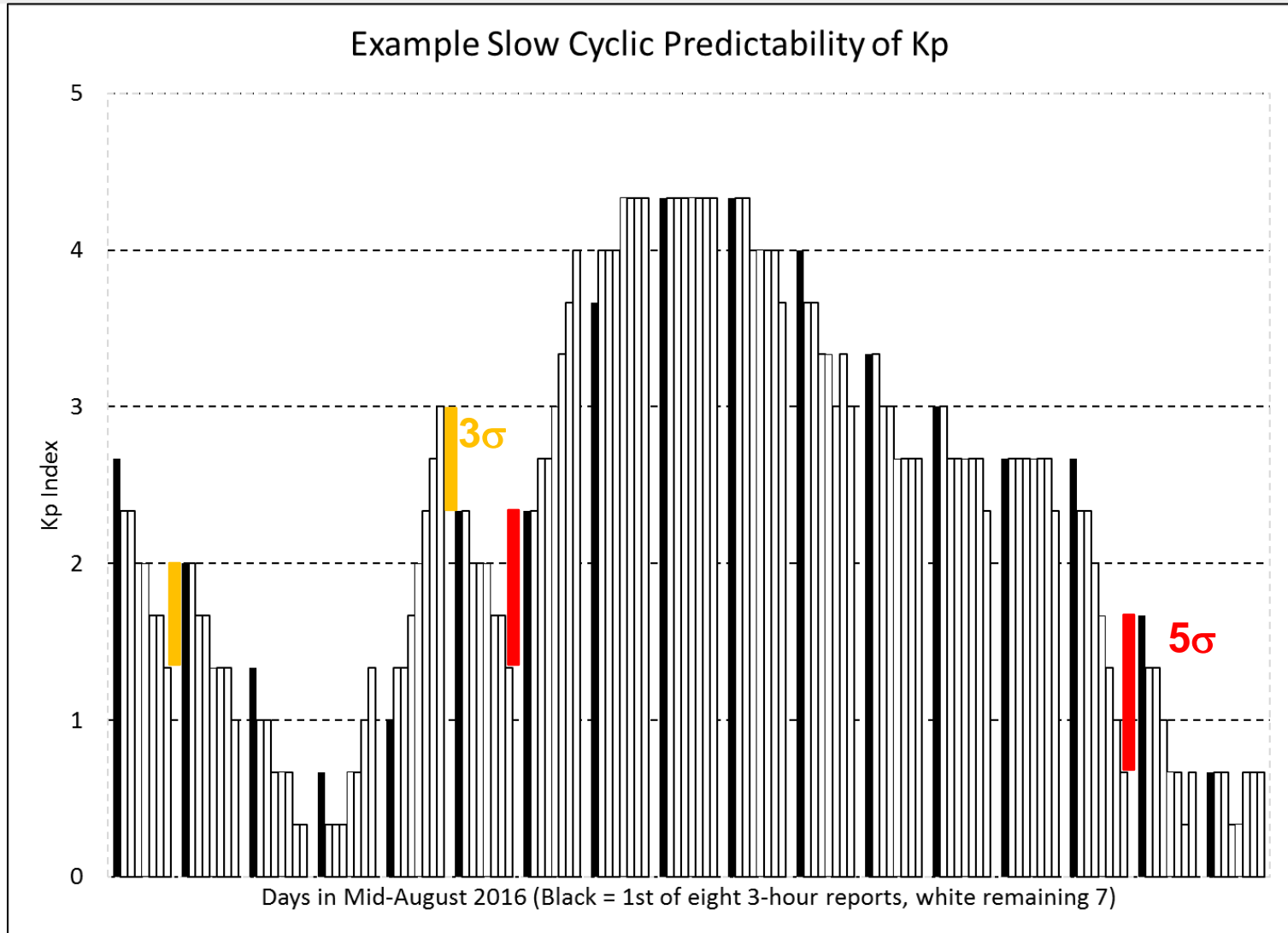


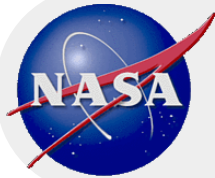
F(10.7) Has Little Effect at Low Altitudes



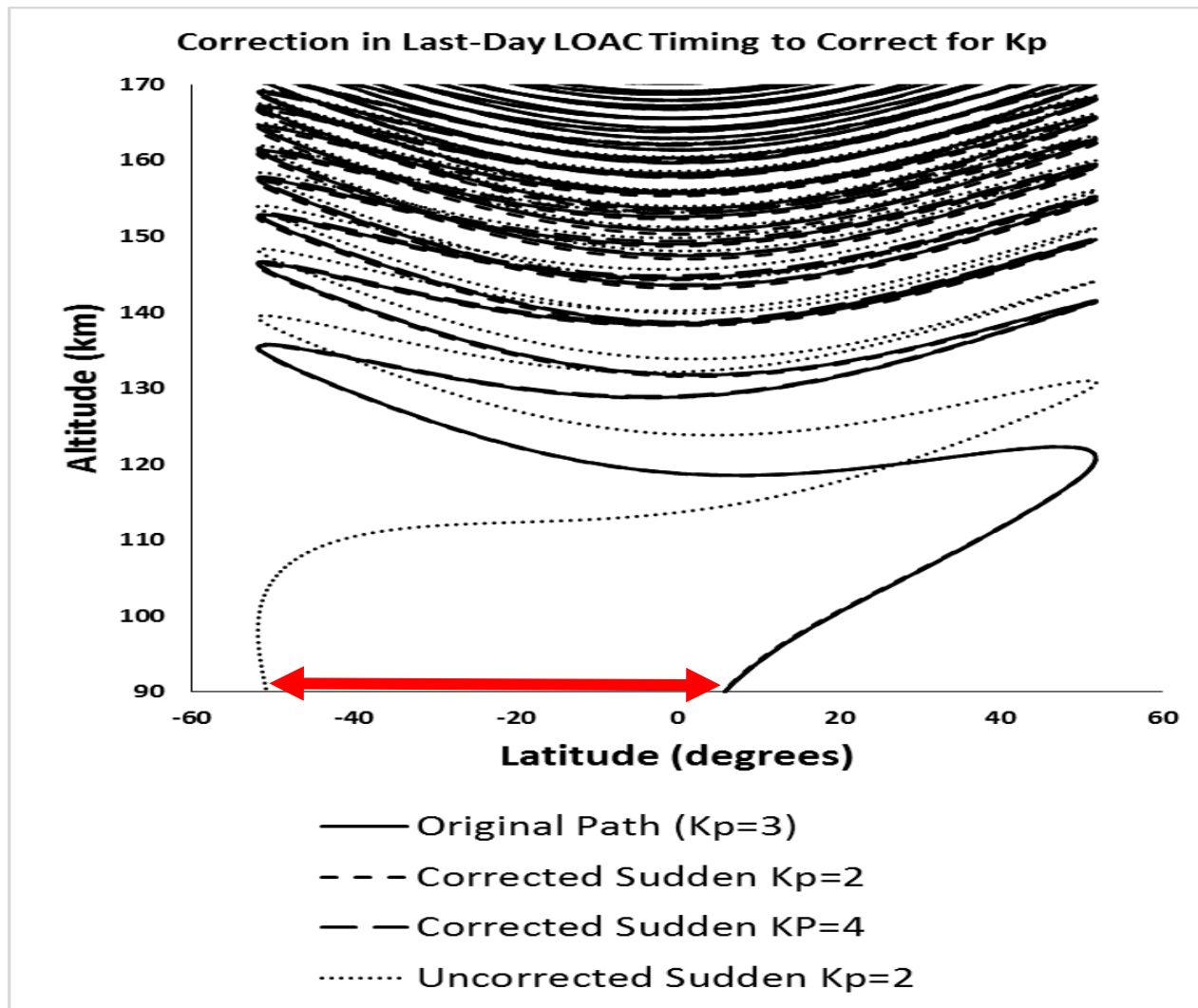


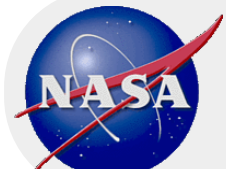
K_p in a 3σ Period in 2016





Environment (and Corrections) Can Exceed Available Target Region in Last ½ Day





Finding a Target Region

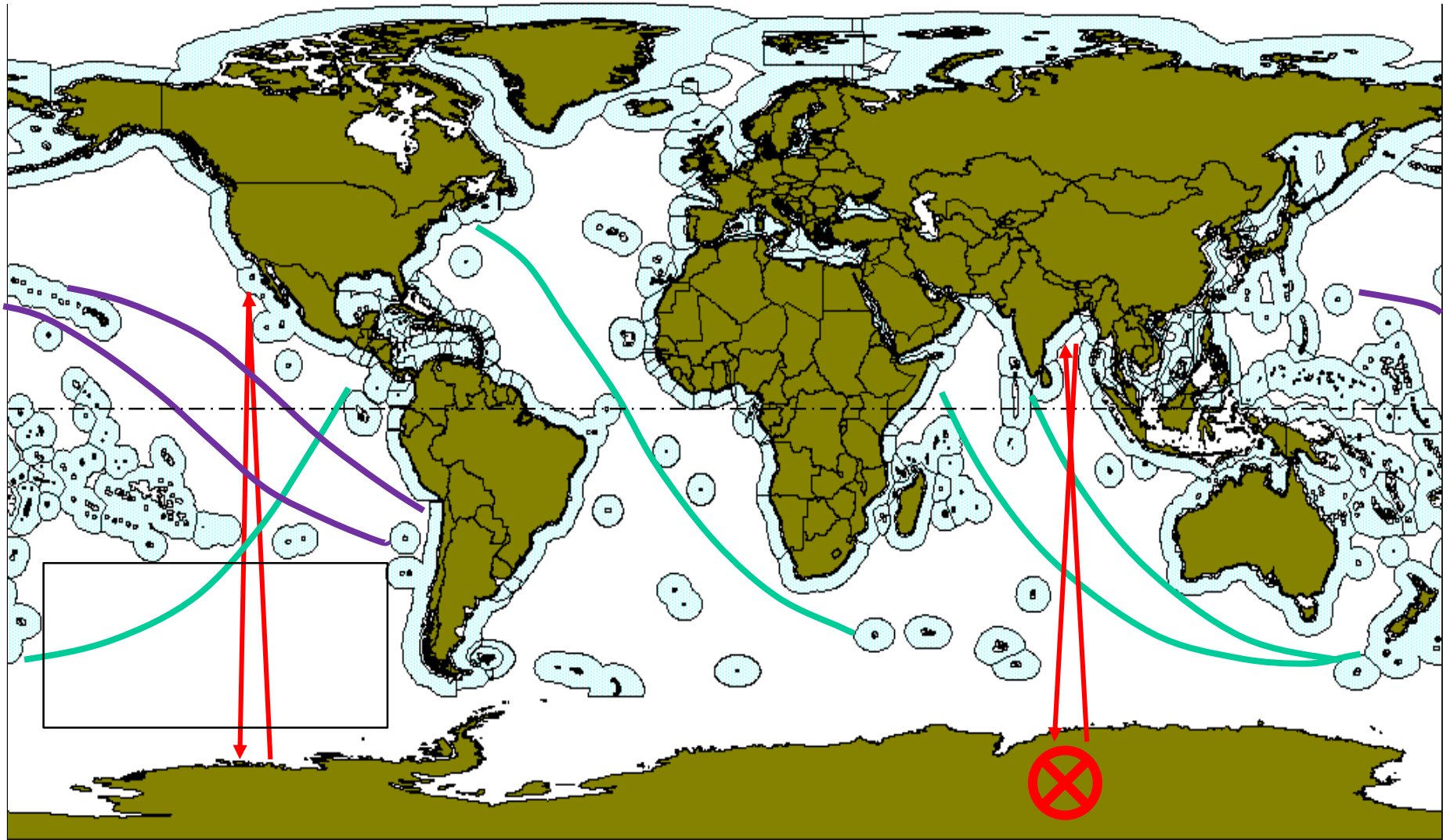


Image: oceanworld.tamu.edu & Polartec.com



Ships at Sea

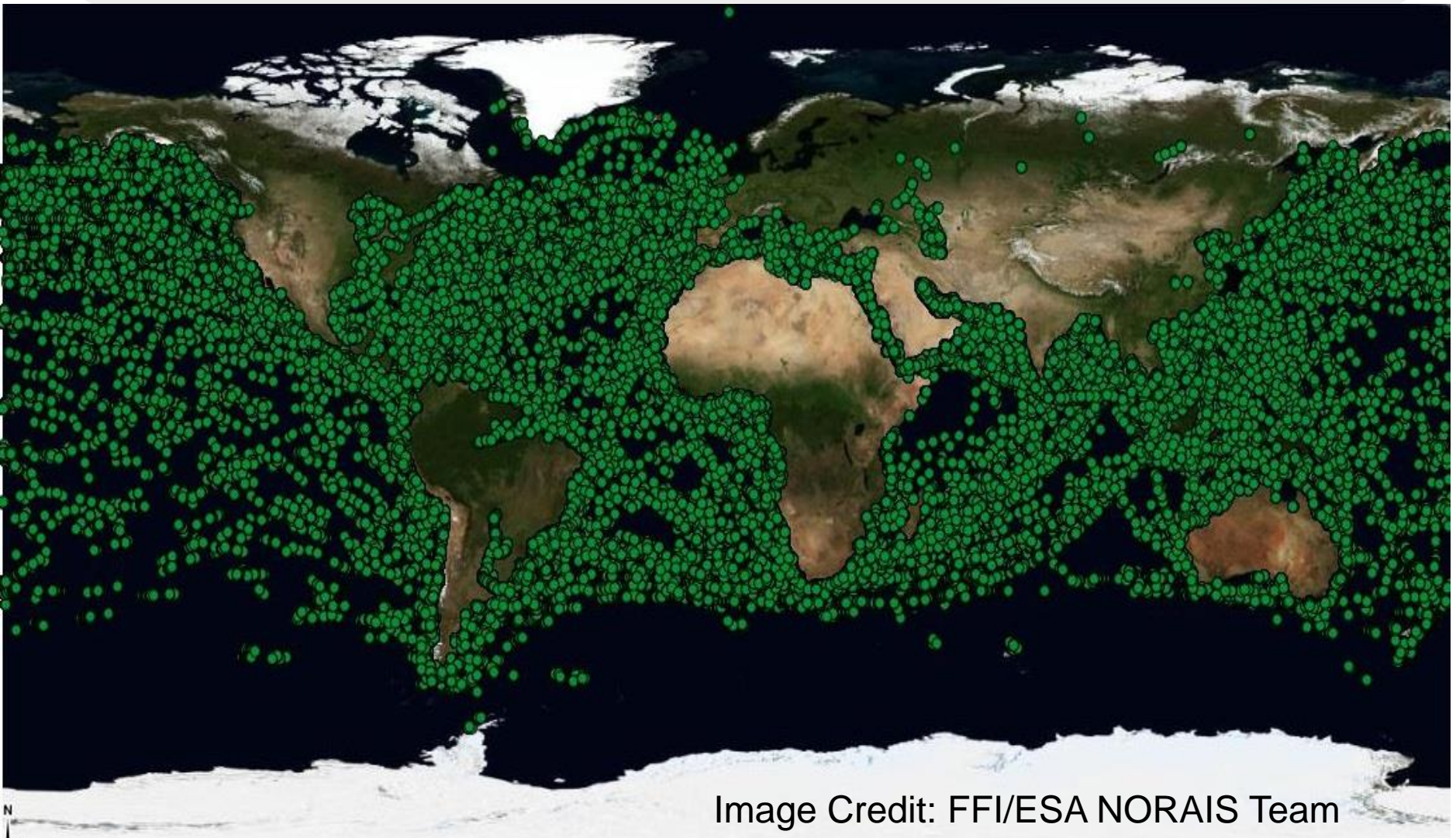
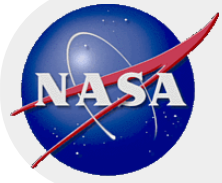
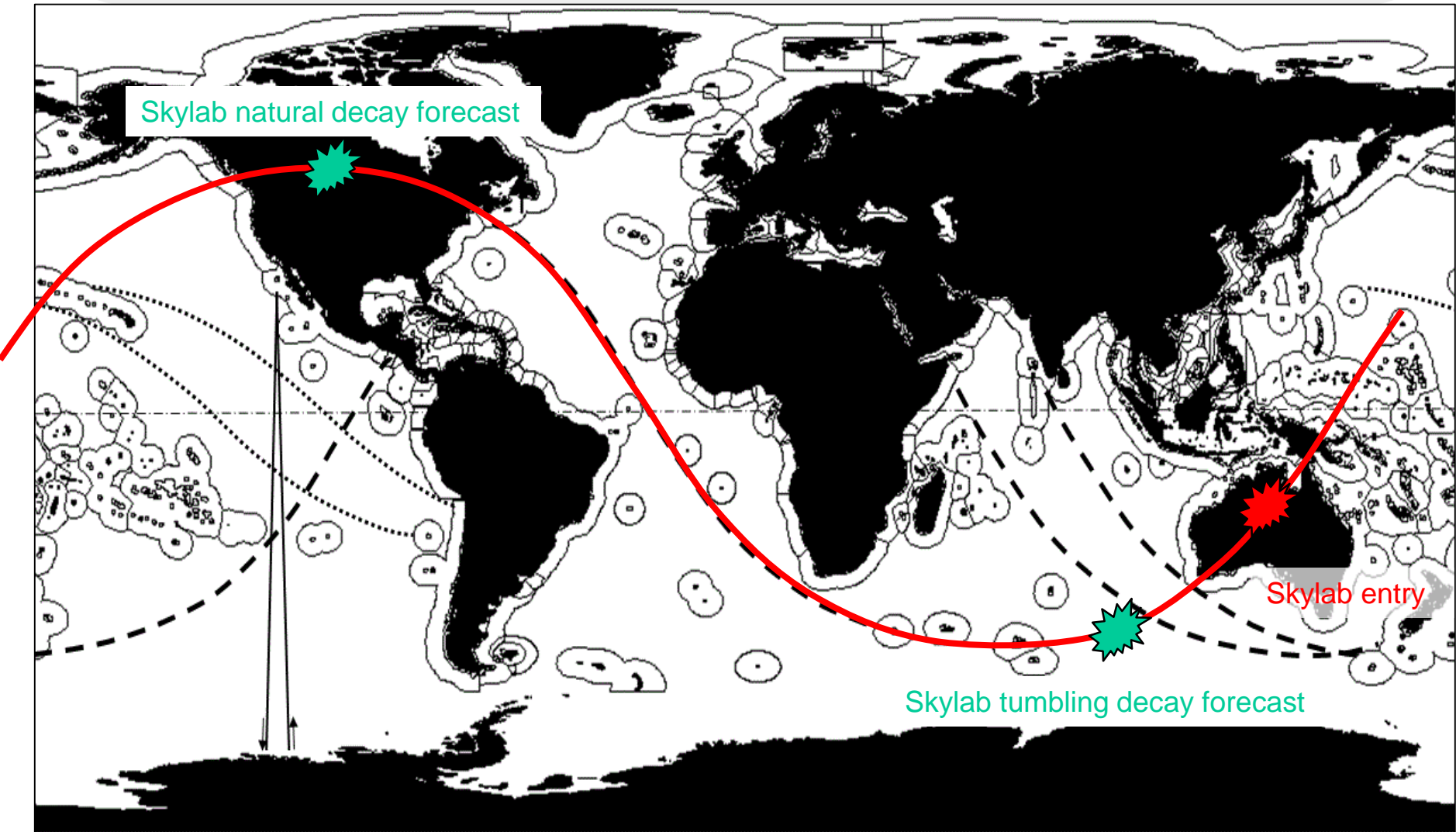
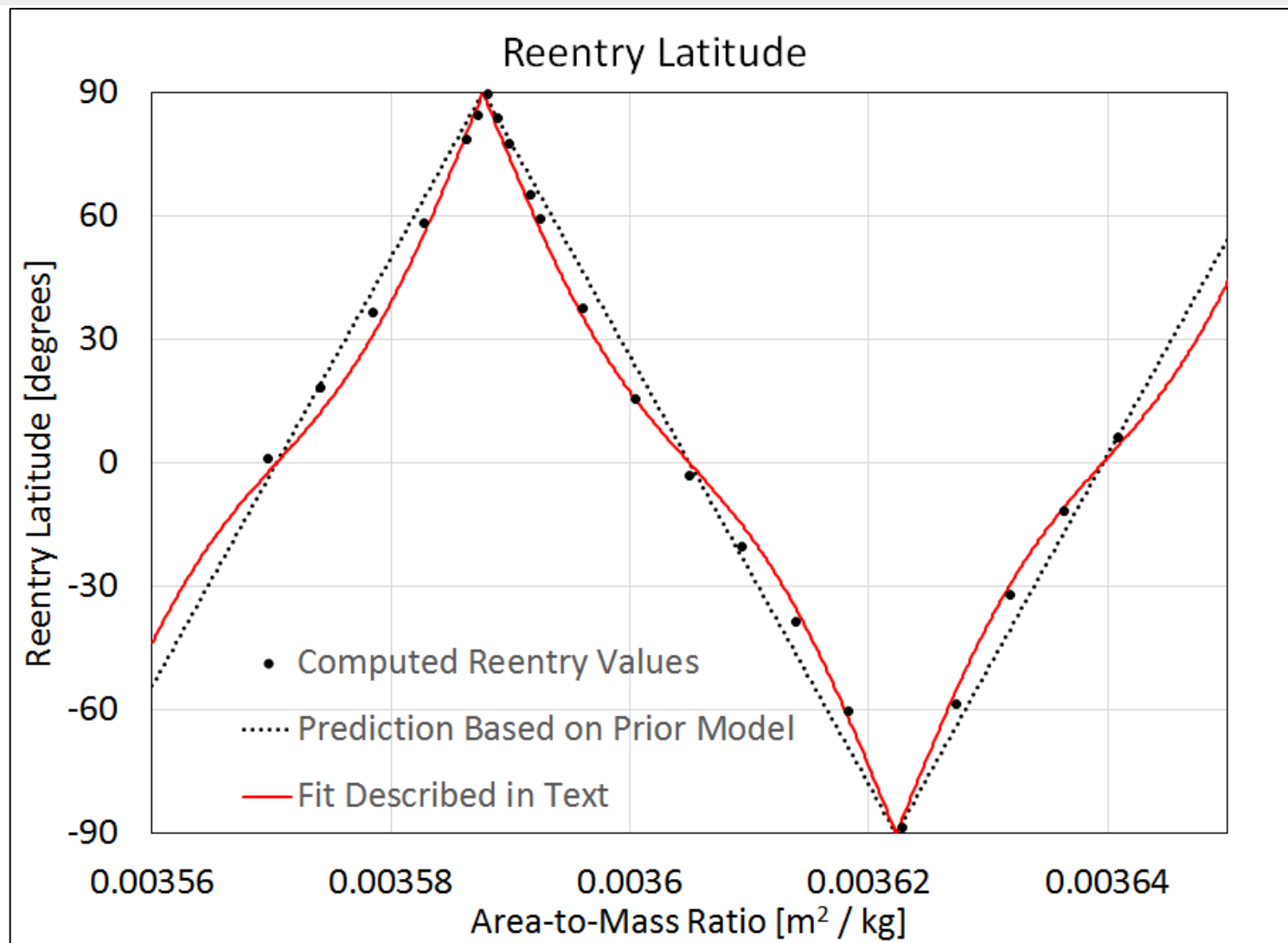


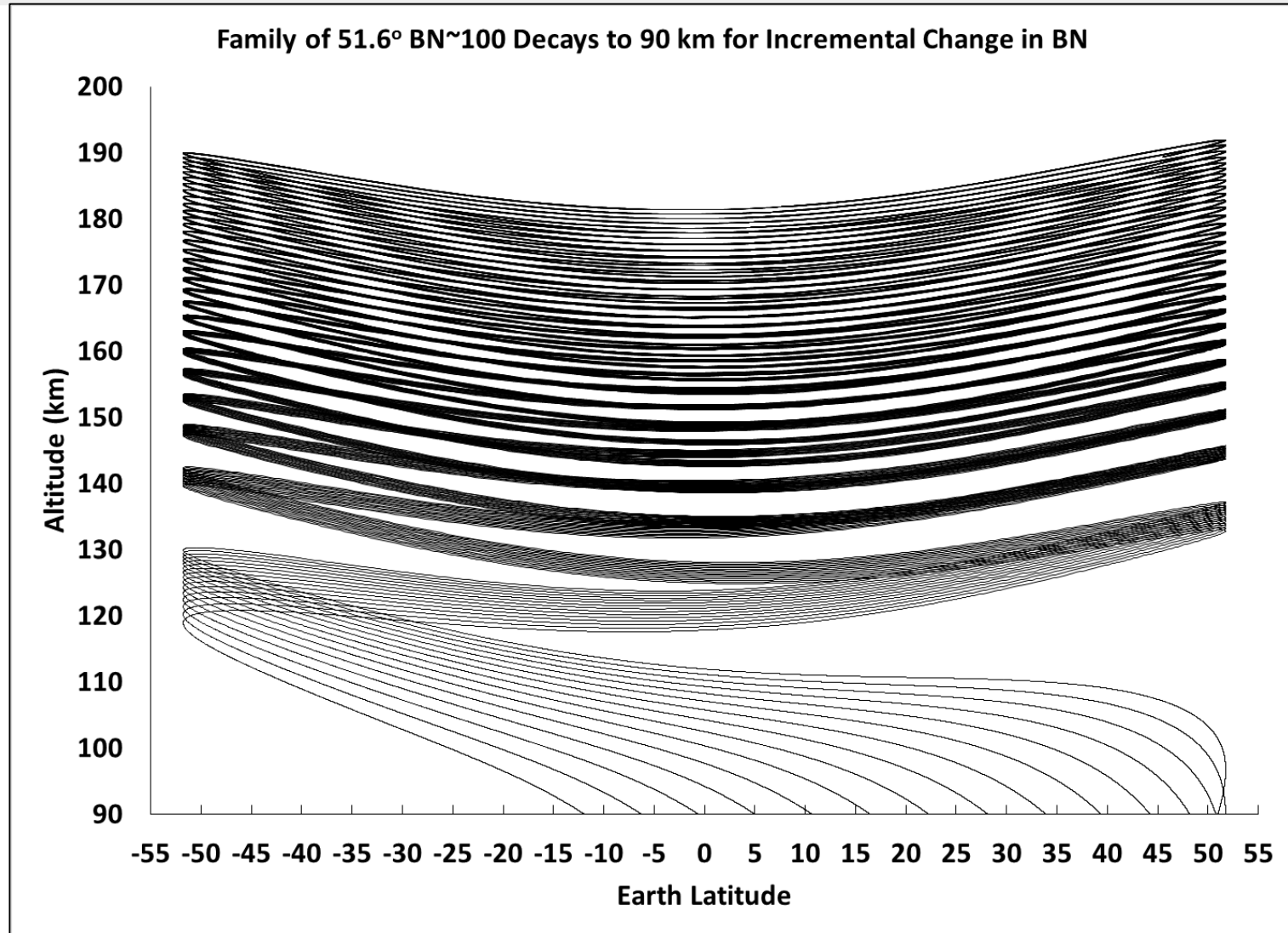
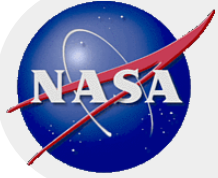
Image Credit: FFI/ESA NORAIS Team

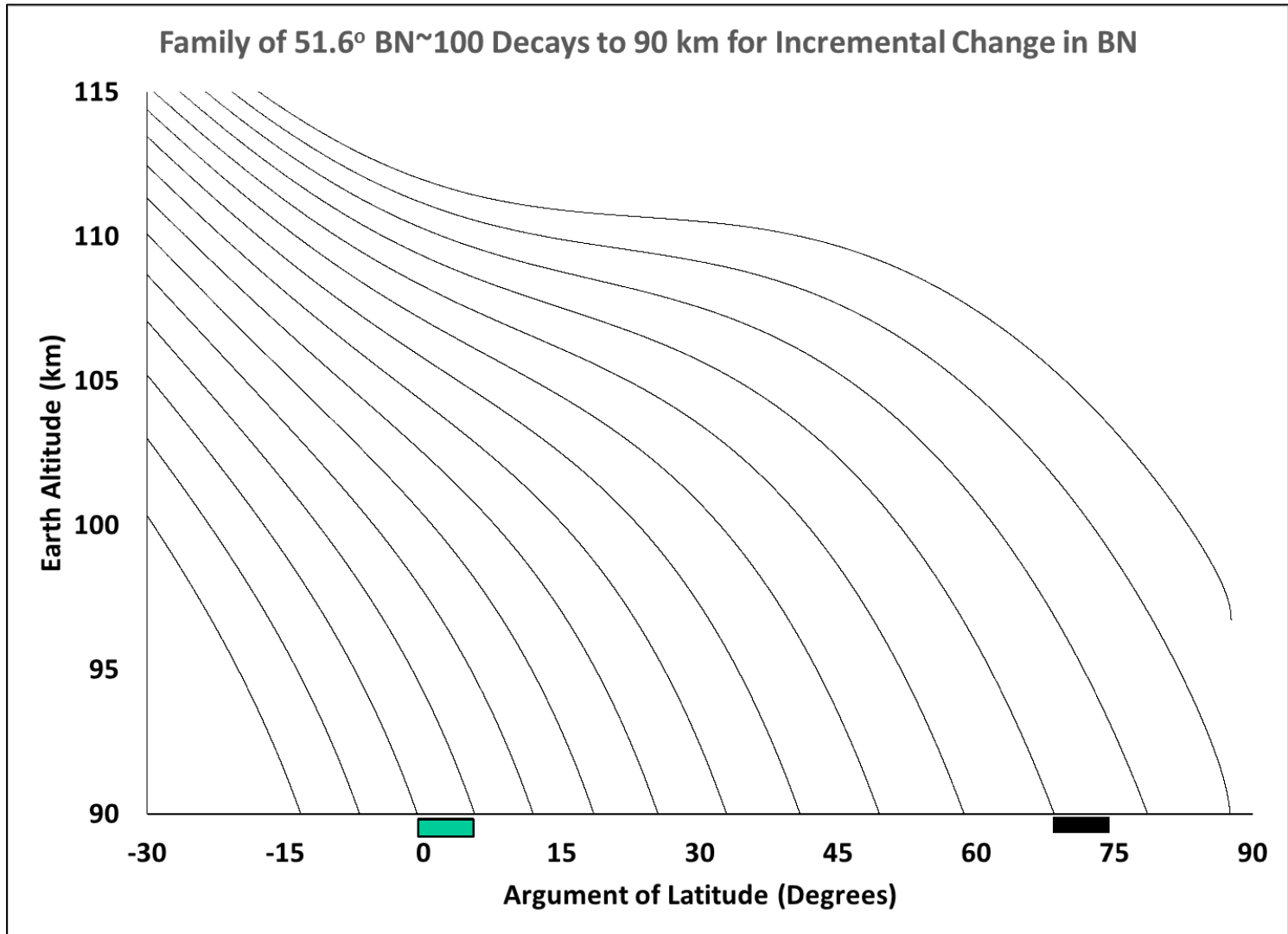


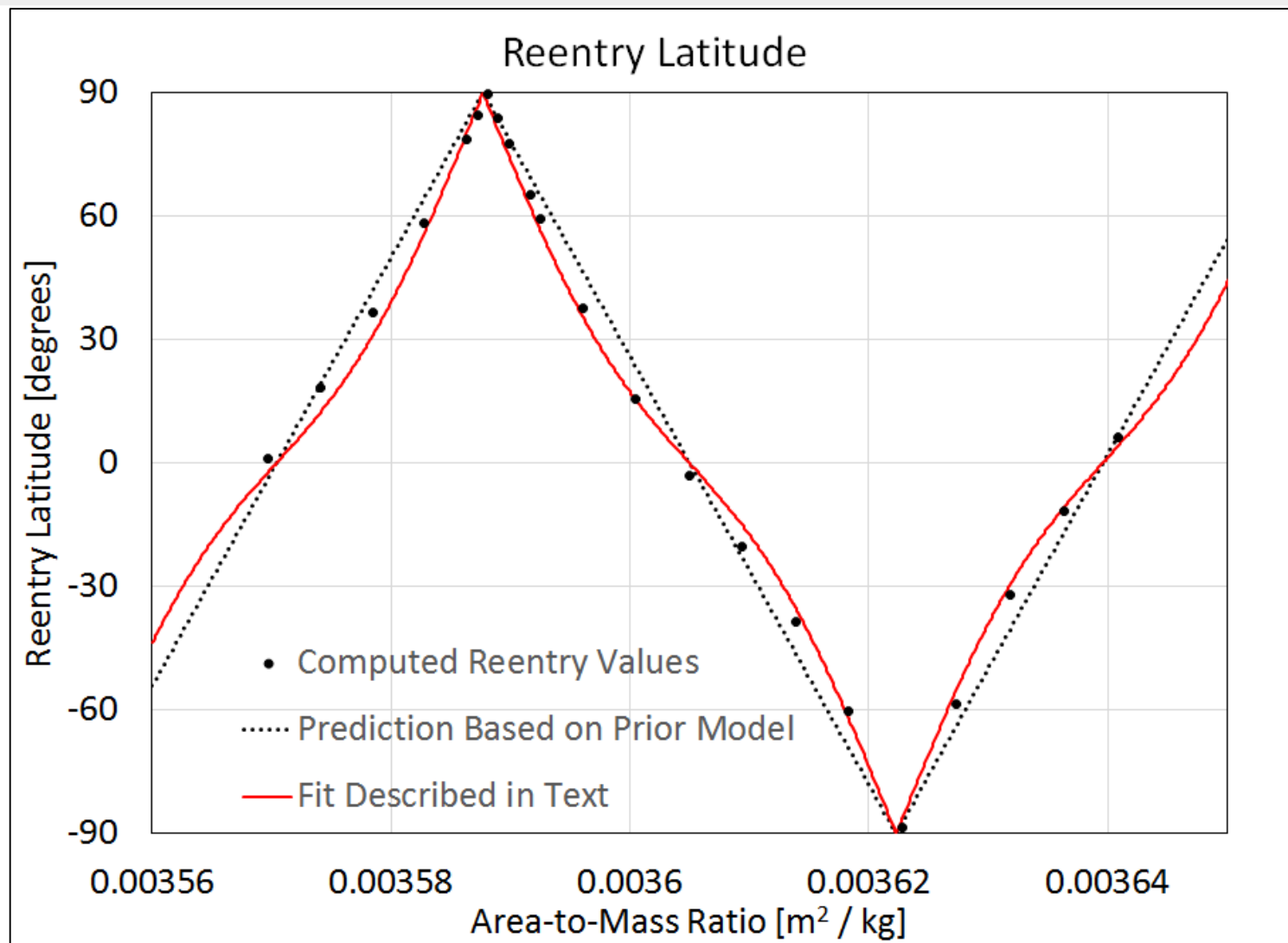
Skylab Decay





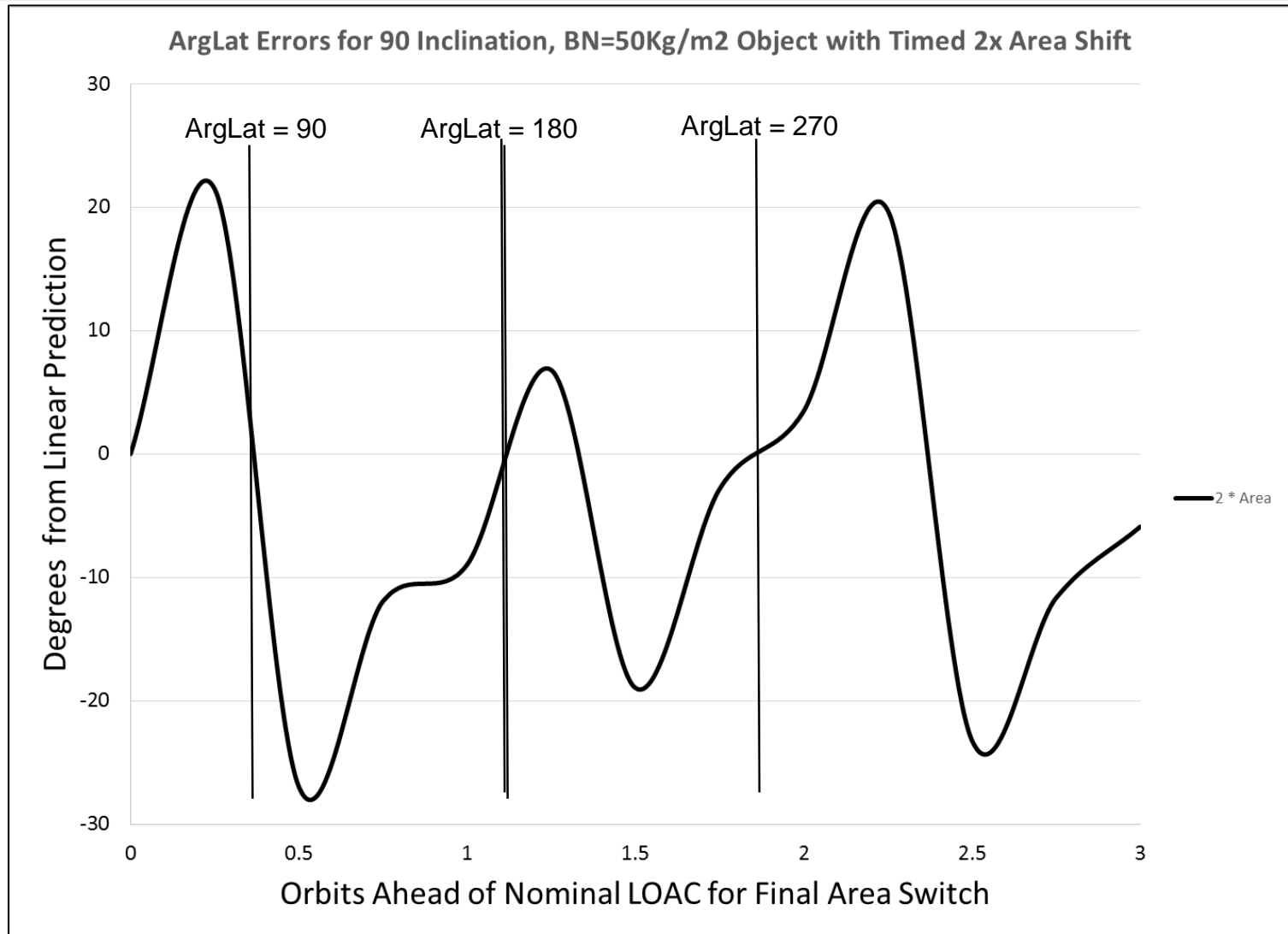


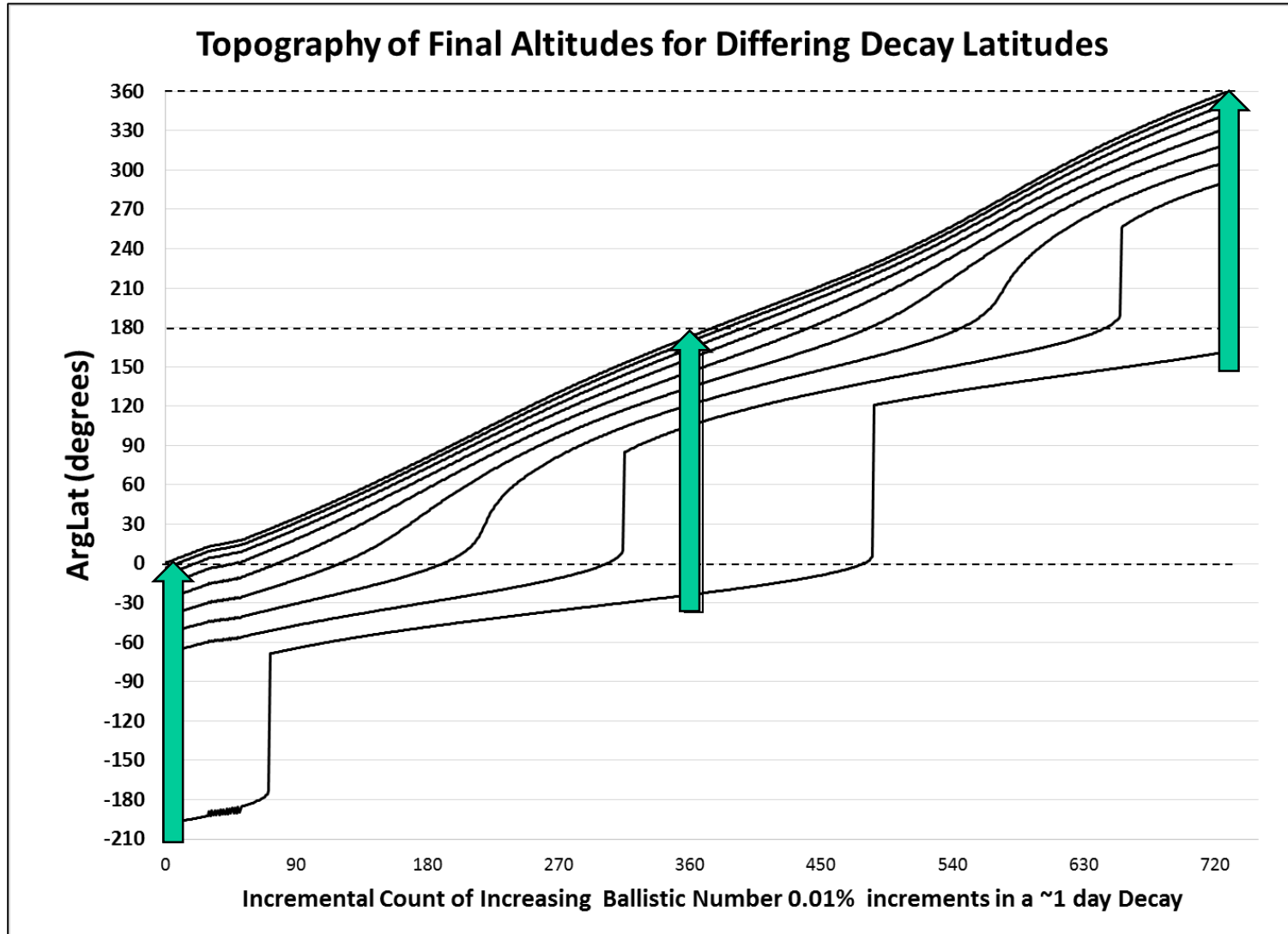






Uprange/Downrange Error







Skylab Entry

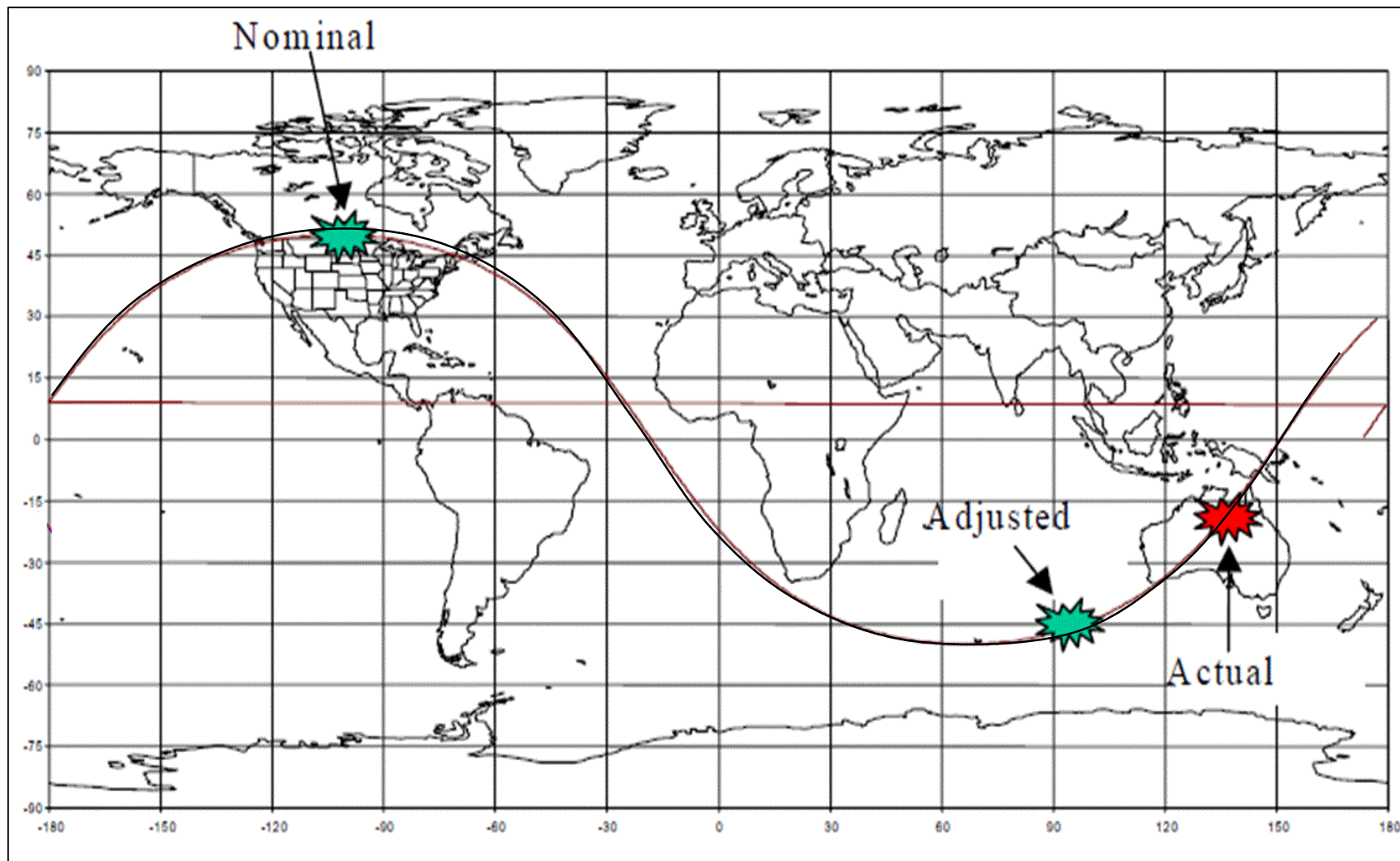
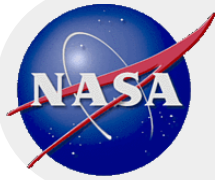
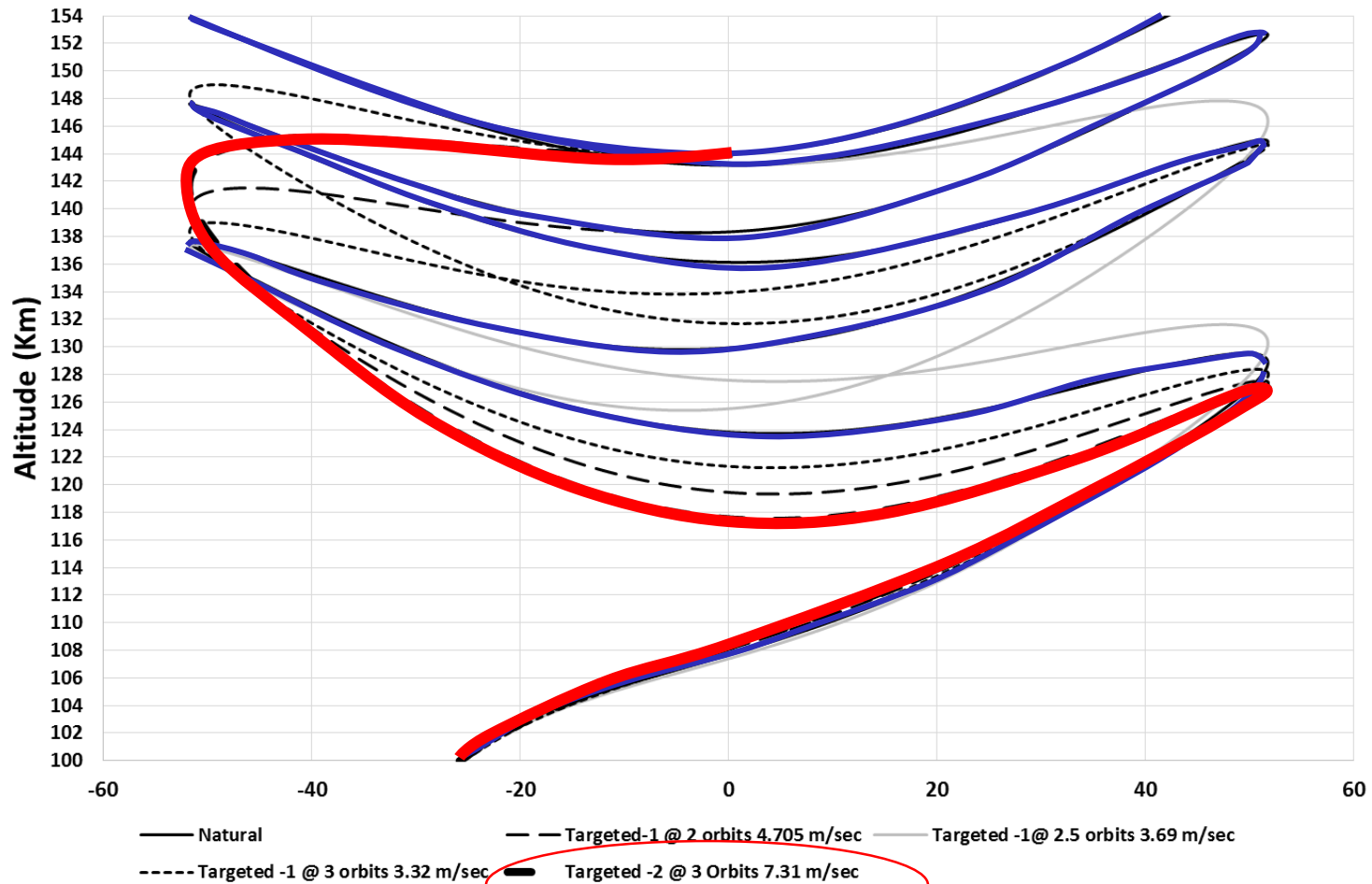


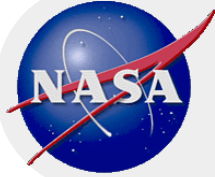
Image: Patera, Russell P. (2005)



7.3 m/sec Applied 3 Orbits Early

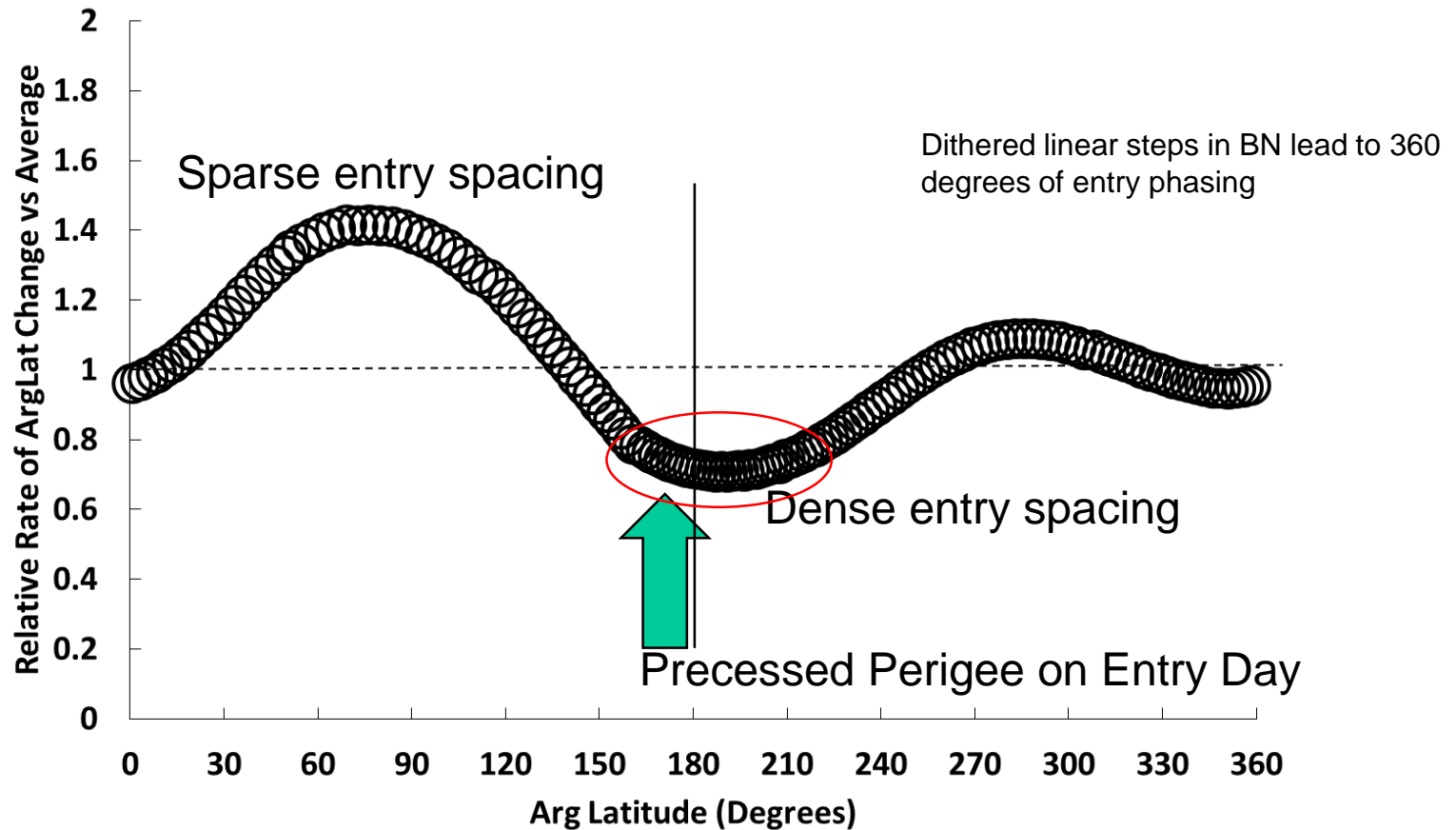
Accelerated Natural Decays of a 100 BN Object @ 51.6 Deg To
Common Latitude

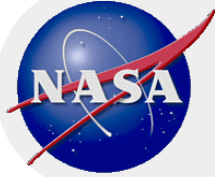




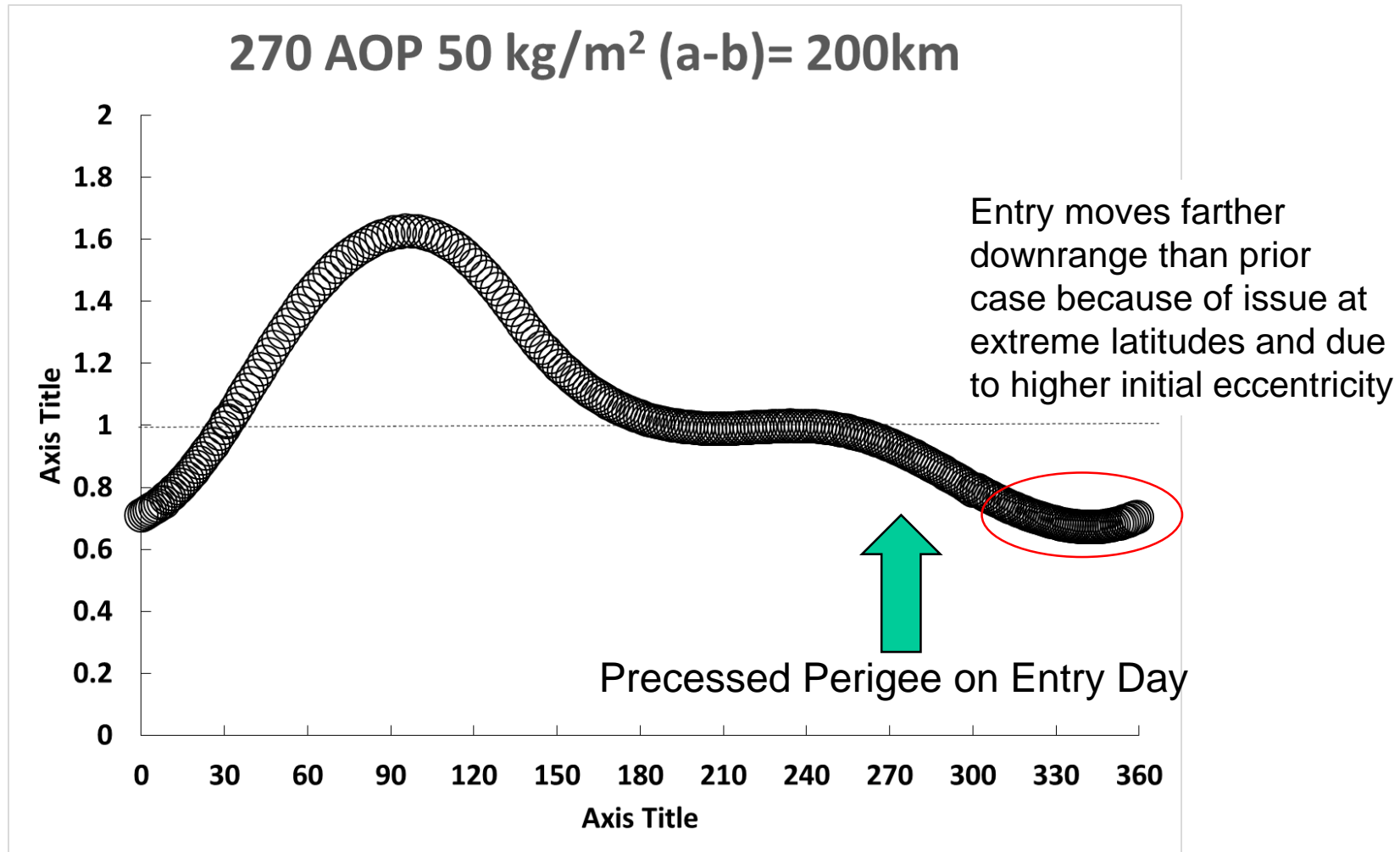
Decay Clustering Near Perigee

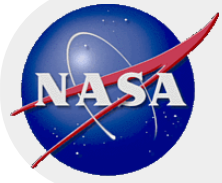
165 AOP 50kg/m² (a-b)=100km



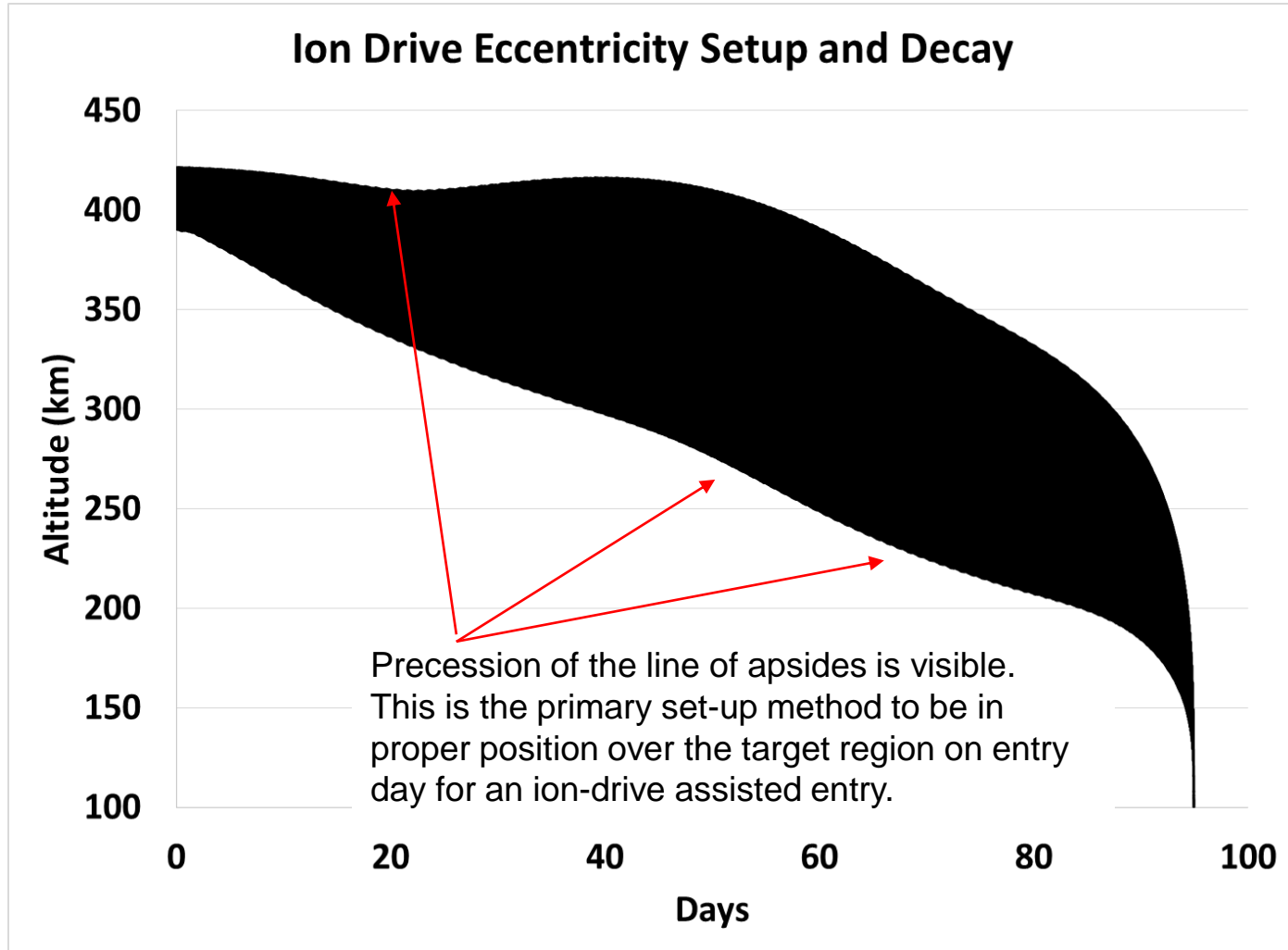


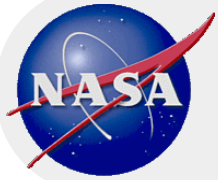
Decay Clustering Near Perigee



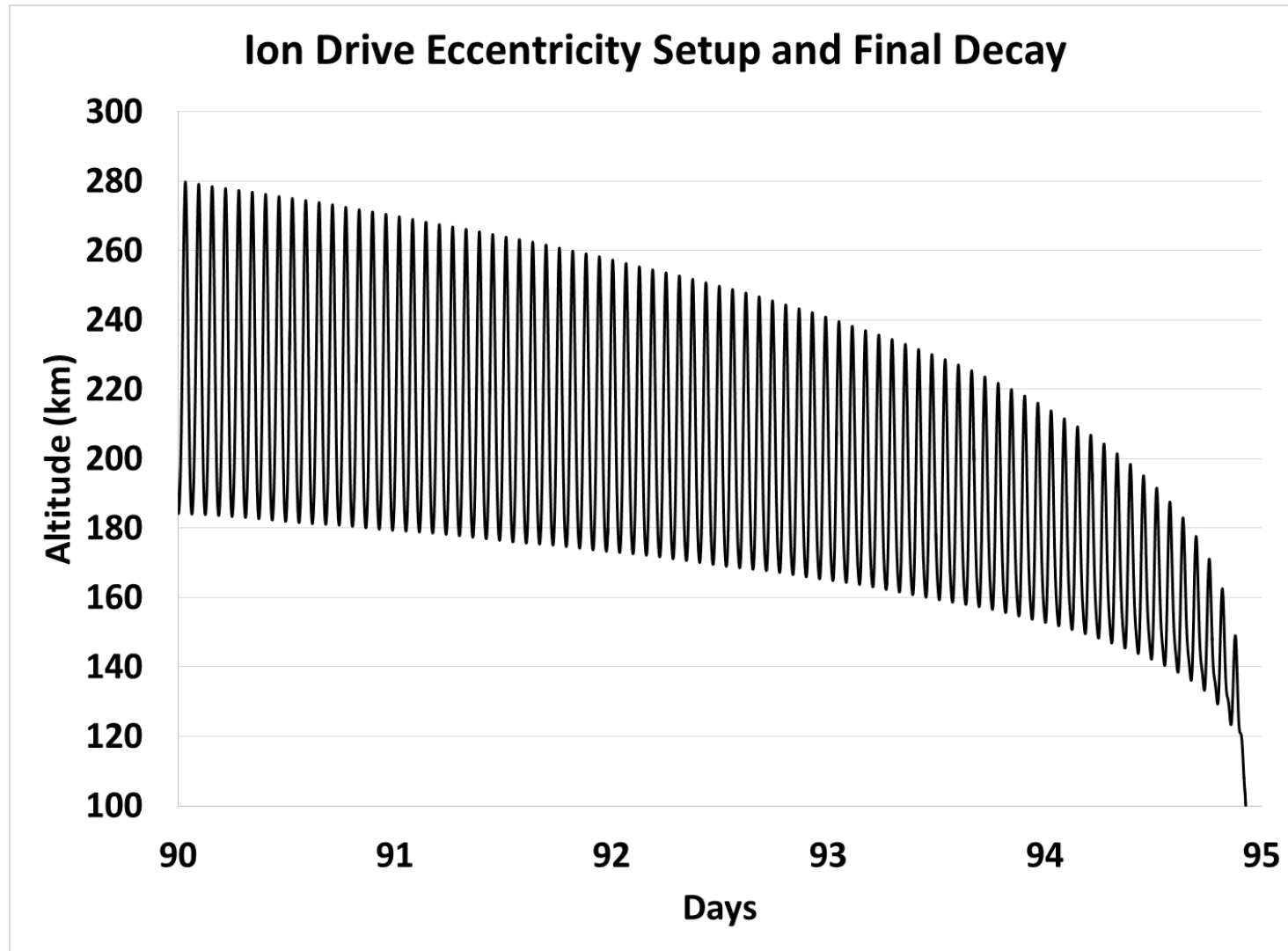


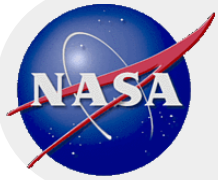
Setting Up Perigee





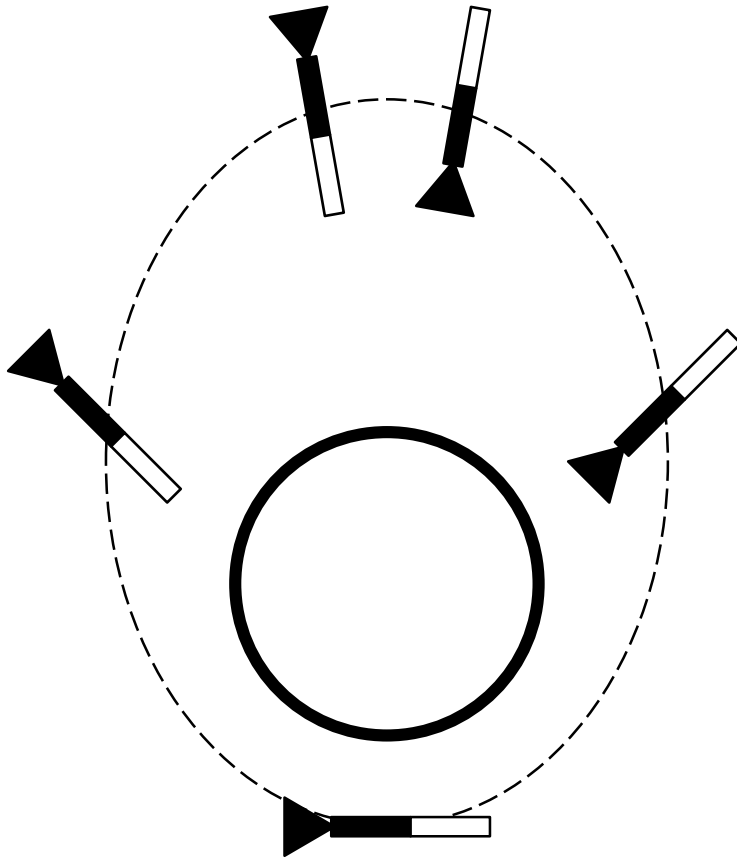
Eccentricity Shrinks, but is Still a Driver



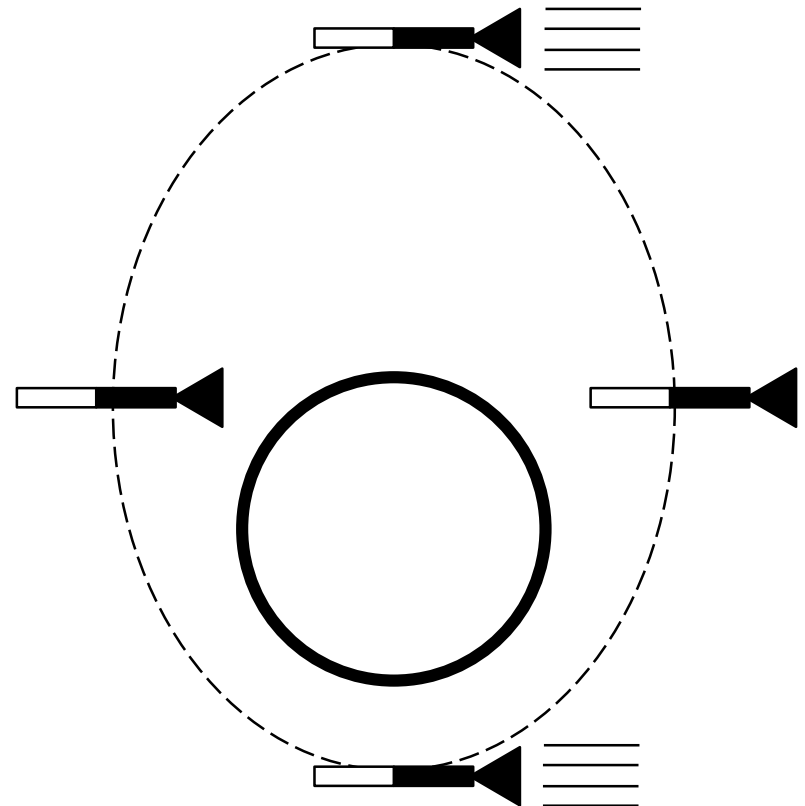


Extra Eccentricity Tricks

Strategic Tumble Modes to Increase Eccentricity



Drag-Based



Thrust-Based



18 Control Points

1. Global Positioning System (GPS) is important
2. Final maneuvering must come very late
3. Requires active control of the spacecraft's area.
4. Must command while under positive control.
5. Reference attitude change timing is one quarter day (4 orbits) before the predicted entry accounting for the transition.
6. Final day of decay is unaffected by the F(10.7) solar flux
7. K_p can be predicted $\ll 3\sigma$ absolute change rate
8. Along-track dispersions are greatest in extreme latitudes
9. Highest possible drag is beneficial in reducing dispersions in the final phases.
10. Put final controllable perigee passes in darkness.
11. Propellant demand numbers in this study assume only one attitude transition
 - However, ongoing projected area control is an opportunity to reduce propellant use in earlier phases.
12. Final selection from among target zones can be made very late (and may help)
13. If the entry requires the longest possible target zone, careful and very early attention (measured in months) is needed to align the ground track
14. All phasing burns should be done to position the perigee just uprange of the footprint area on entry day.
15. Eccentricity should be maximized while meeting all other constraints.
16. One can use one-half orb-rate tumble to add to the eccentricity, in the right conditions.
17. One can use solar-inertial attitude and every-half-orbit firing to exaggerate eccentricity.
18. In ion propulsion, there is a trade to be made on which eccentricity enhancement mode is preferable
 - In conventional-thrust or zero-thrust cases, only the drag mode would apply.